PB-217 427

PHYSICAL PROPERTIES OF SEVERAL COMMERCIAL FILTER AIDS. PART II

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1 September 1968

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FINAL REPORT
PART II OF VI PARTS

Physical Properties of Several Commercial Filter Aids

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Submitted to:
U.S. Army Engineer Research and Development Laboratories
(Contract DAAK02-67-C-0408)
Fort Belvoir, Virginia

ERI – 267
Project No. 684-S

September 1, 1968

SANITARY ENGINEERING SECTION
ENGINEERING RESEARCH INSTITUTE
IOWA STATE UNIVERSITY AMES

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INTRODUCTION

General

Diatomite and perlite filter aids are granular materials consisting essentially of amorphous silica. Equivalent grades* of either material have physical properties that may differ substantially because of the differences in raw material and processing methods used in preparing the finished product.

Diatomite consists of the skeletal remains of microscopic, aquatic plants called diatoms. Deposits of diatomite are found in various parts of the world as loosely cemented sedimentary rock. After quarrying, diatomite is processed for use as a filter aid by drying, crushing, calcining, and classifying into various grades. The various grades differ in particle size distribution, bulk density, hydraulic characteristics, and filtering effectiveness. Diatoms have diverse shapes and are characterized by their intricate structure. After processing, the filter aid contains whole particles, fragments and microscopic aggregates (built up by flux calcining). The particles in diatomite do not pack because contact is limited to the outer edges of each particle. The particles are not compressible and the filter aid cannot be crushed unless subjected to a relatively great force.

Perlite is a material similar to diatomite in outward appearance and in hydraulic characteristics. Perlite is prepared by processing a siliceous, igneous rock (also known as perlite) containing 3 to 5% water.

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*Equivalent grades are those which provide essentially equivalent filter performance, or provide the same quality of effluent with the same filter run hydraulic characteristics.

When crushed and heated during processing, the rock expands to provide a mass of glass bubbles which is twenty or more times its original volume. When this foam-like structure is milled and classified, a product consisting of irregular fragmented particles is produced. Filter cakes containing perlite filter aids have a high porosity and are not compressible unless subjected to a relatively great force.

Either diatomite or perlite filter aids may be used for removing suspended solids from water. When added in correct proportion to the suspended solids in the water to be filtered, these filter aids produce a reasonably permeable filter cake capable of trapping submicron size particles in an economical filter run. The correct proportions can be determined by filtration tests. If too little filter aid is used, the headloss builds up rapidly and the filter runs are too short. If too much filter aid is used, the headloss buildup is so slow that the filter run terminates at a headloss below the design capabilities of the filter plant.

Purpose of This Study

The purpose of this study was to characterize some of the filter aids suitable for water filtration in terms of those physical characteristics related to their effectiveness in the filtration process. The important physical characteristics of a filter aid include particle size and shape, and the volume of voids in the cake as it is formed on a filter septum for use in filtration.

A particle size analysis of a filter aid can be made using a variety of methods including the hydrometer method, the Coulter Counter method,

and others. The particle size distributions obtained using various methods do not necessarily agree unless the particles are spherical. Any of the methods can be used for determining the particle size of diatomite but the hydrometer method cannot be used with perlite because of the variable specific gravity of particles in this type of filter aid.

To determine the volume of voids in a filter cake, it is necessary to determine both the effective specific gravity and the bulk density of the filter aid in the filter cake. The effective specific gravity of the filter aid, ρ_F, is defined as the ratio of the weight of a unit volume of filter aid to the weight of a unit volume of water at 20°C and is expressed in dimensionless terms. The bulk density of the filter media, γ_F, is defined as the weight of the filter aid per unit volume of a filter cake as it is formed in filtration. The bulk density of the filter media is usually expressed in units of pounds per cubic foot (pcf).

The void volume of a filter medium is related to its bulk density and effective specific gravity as expressed in the equation:

$$f = \frac{\text{volume of voids in filter cake}}{\text{volume of filter cake}}$$

$$= \frac{\gamma_W - \gamma_F/\rho_F}{\gamma_W}$$

$$= \left(1 - \frac{\gamma_F}{\gamma_W \rho_F}\right) \qquad (1)$$

where f = porosity (or void ratio) of filter medium [−]*

γ_W = density of water, $[FL^{-3}]$

γ_F = bulk density of filter aid, $[FL^{-3}]$

ρ_F = effective specific gravity of filter media, [−]*.

---

*[−] dimensionless units.

Approach Used in Study

Eleven grades of diatomite and perlite filter aids from four manufacturers were tested to determine the following physical properties of each:

- particle size distribution,
- effective specific gravity,
- bulk density,
- filter cake resistance.

Codes, consisting of a letter and a number, were used to designate each of the filter aid grades. A different letter was used for each manufacturer. Filter aids S2, S3, and S4 are perlite filter aids; filter aids J4, J3, J0, E6, E5, E2, G4, and G1 are diatomite filter aids. A total of 144 separate filter aid samples were included in the study. Of these, 126 were tested in one or more ways, and 31 were subjected to the full series of physical tests as well as a filtration test with an iron-bearing water*. Table 1 gives a description of each sample and indicates the tests that were run on each.

---

*The results of filtration tests using 34 filter aids to filter water are included in Part I of this report entitled "Filtration Resistance of Several Commercial Filter Aids."

Table 1. Filter aid samples included in this study.

Filter aid grade	Lot number	Sample size, lb	Source	Description	Tests made[a]
S2	1	50	Manufacturer	–	FC PpS
	2	50	Manufacturer	–	P
	3	50	Manufacturer	–	FC P S
	4	50	Manufacturer	–	FC PpS
	5	50	Manufacturer	–	F PpS
	6	50	Manufacturer	–	F PpS
	7	50	Manufacturer	–	P
	8	50	Manufacturer	–	P
	9	50	Manufacturer	–	F PpS
	10	50	Manufacturer	–	P
	11	50	Manufacturer	–	P
	12	50	Manufacturer	–	P
	13	50	Manufacturer	–	P
	14	50	Manufacturer	–	P
	15	50	Manufacturer	–	P
	16	50	Manufacturer	–	P
	17	50	Manufacturer	–	P
	18	50	Manufacturer	–	P
	19	50	Manufacturer	–	P
	20	50	Manufacturer	–	F PpS
	21	50	ERDL	–	F PpS
S3	1	50	Manufacturer	–	FC PpS
	2	50	Manufacturer	–	FC PpS
	3	50	Manufacturer	–	FC PpS
	4	50	Manufacturer	–	F PpS
S4	1	50	Manufacturer	–	FC PpS
	2	50	Manufacturer	–	FC PpS
	3	50	Manufacturer	–	FC PpS
	4	50	Manufacturer	–	P
	5	50	Manufacturer	–	–
	6	50	Manufacturer	–	–
	7	50	Manufacturer	–	–
J4	1	50	ISU stocks	–	–
	2	50	ISU stocks	–	–
	3	50	ISU stocks	–	H S
	4	50	ERDL	–	F HPpS
	5	50	Manufacturer	–	P
	6	50	Manufacturer	–	F H S
	7	50	Manufacturer	–	F HPpS
	8	50	Manufacturer	–	P
	9	50	Manufacturer	–	P
	10	50	Manufacturer	–	P

Table 1. Continued.

Filter aid grade	Lot number	Sample size, lb	Source	Description	Tests made[a]
J3	1	50	ISU stocks	–	–
	2	50	ISU stocks	–	–
	3	50	ISU stocks	–	–
	4	50	ISU stocks	–	–
	5	50	Area distributor	–	FCHPpS
	6	50	Area distributor	–	FC
	7	50	ERDL	–	FCHPpS
	8	10	Manufacturer	–	HP
	9	10	Manufacturer	–	HP
	10	10	Manufacturer	–	P
	11	10	Manufacturer		P
	12	10	Manufacturer		P
	13	10	Manufacturer		HP
	14	10	Manufacturer	Samples from	HP
	15	10	Manufacturer	ten separate	HP
	16	10	Manufacturer	shifts	P
	17	10	Manufacturer		HP
	18	10	Manufacturer		P
	19	10	Manufacturer		HP
	20	10	Manufacturer		HP
	21	10	Manufacturer		P
	22	10	Manufacturer	Samples from	HP
	23	10	Manufacturer	each hour	P
	24	10	Manufacturer	of one	P
	25	10	Manufacturer	shift	HP
	26	10	Manufacturer		P
	27	10	Manufacturer		HP
J0	1	50	ERDL	–	F HPpS
	2	10	Manufacturer	–	HP
	3	10	Manufacturer	–	HP
	4	50	Manufacturer	–	F HPpS
	5	50	Manufacturer	–	HP
	6	50	Manufacturer	–	F P
	7	50	Manufacturer	–	P
	8	50	Manufacturer	–	P
E6	1	50	Manufacturer	–	H
	2	50	Manufacturer	–	F HPpS
	3	50	Manufacturer	–	F H pS
	4	50	Manufacturer	–	F HPpS
	5	10	Manufacturer	–	–
	6	10	Manufacturer	–	–
	7	50	Manufacturer	–	–
	8	50	Manufacturer	–	–
	9	50	Manufacturer	–	–
	10	50	Manufacturer	–	–

Table 1. Continued.

Filter aid grade	Lot number	Sample size, lb	Source	Description	Tests made[a]
E5	1	50	ERDL	–	F HPpS
	2	50	Manufacturer	Lot A	HP
	3	50	Manufacturer	Lot A	F HPpS
	4	50	Manufacturer	Lot A	HP
	5	50	Manufacturer	Lot A	HP
	6	50	Manufacturer	Lot B	HP
	7	50	Manufacturer	Lot B	HP S
	8	50	Manufacturer	Lot B	HP S
	11	50	Manufacturer	Lot B	HP S
	12	50	Manufacturer	Lot B	P
	17	50	Manufacturer	Lot B	F HPpS
	9	50	Manufacturer	Lot C	HP
	10	50	Manufacturer	Lot C	HP S
	13	50	Manufacturer	Lot C	HP
	14	50	Manufacturer	Lot C	HP S
	15	50	Manufacturer	Lot C	HP S
	16	50	Manufacturer	Lot C	HP S
	18	10	Manufacturer	(Samples	P
	19	10	Manufacturer	from	P
	20	10	Manufacturer	each	P
	21	10	Manufacturer	hour	P
	22	10	Manufacturer	of one	P
	23	10	Manufacturer	shift	P
	24	10	Manufacturer	of	P
	25	10	Manufacturer	Lot C)	P
	26	10	Manufacturer	–	P
	27	10	Manufacturer	–	P
	28	10	Manufacturer	(Samples	HP
	29	10	Manufacturer	from each	HP
	30	10	Manufacturer	shift	HP
	31	10	Manufacturer	over	HP S
	32	10	Manufacturer	several	HP S
	33	10	Manufacturer	days –	HP
	34	10	Manufacturer	–	HP
	35	10	Manufacturer	–	HP
	36	10	Manufacturer	–	P
	37	10	Manufacturer	–)	HP
E2	1	50	Manufacturer	–	F HPpS
	2	50	Manufacturer	–	F HPpS
	3	50	Manufacturer	–	F HPpS
	4	50	Manufacturer	–	F HPpS
	5	10	Manufacturer	–	PpS
	6	10	Manufacturer	–	P
	7	50	Manufacturer	–	–
	8	50	Manufacturer	–	–
	9	50	Manufacturer	–	–
	10	50	Manufacturer	–	–

Table 1. Continued.

Filter aid grade	Lot number	Sample size, lb	Source	Description	Tests made[a]
G4	1	50	ERDL	–	F HPpS
	2	50	Manufacturer	–	F HPpS
	3	50	Manufacturer	–	F HPpS
	4	50	Manufacturer	–	F HPpS
	5	50	Manufacturer	–	F HPpS
G1	1	50	ERDL	–	F HP S
	2	50	Manufacturer	–	F HPpS
	3	50	Manufacturer	–	F HPpS
	4	50	Manufacturer	–	HP S
	5	50	Manufacturer	–	F HP

[a] Key: F Filtration test
C Particle size analysis by Coulter Counter method
H Particle size analysis by hydrometer method
P Bulk density and filter cake resistance – old equipment
p Bulk density and filter cake resistance – new equipment and standard procedure
S Specific gravity

ANALYTICAL METHODS

General

Four different analytical methods were used to determine the physical properties of the filter aids included in this study. Two of the methods are well-known methods for determining the particle size distribution of granular materials:

- Coulter Counter method,
- hydrometer method.

A third analytical method developed for use in this study was based on the procedure used in soil testing for determining the effective specific gravity of soil particles:

- pycnometer method.

The fourth analytical method was devised and used both to determine the in-place bulk density of the filter aid in a filter cake and to determine the filter cake resistance (or permeability):

- permeameter method.

Coulter Counter Method[2]

The Coulter Counter can be used to determine the number and size of particles suspended in an electrically conductive liquid. This is done by forcing the suspension to flow through a small aperture having an immersed electrode on either side. As a particle passes through the aperture, it changes the electrical resistance between the electrodes. This produces a voltage pulse of short duration having a magnitude proportional to the particle volume. The series of pulses (particles passing the aperture) is then electronically scaled and counted.

The instrument used in this study was a Coulter Counter Model B*, a dual threshold instrument costing about $6000. Threshold refers to the lowest voltage pulse that will be counted by the instrument with a given combination of control settings. Since particle size is proportional to voltage, the threshold level also refers to the smallest particle that will be counted. A dual threshold instrument counts voltage pulses or particles that are in a given size range. The instrument settings can be made so that successive counts cover a complete particle size distribution.

Filter aids were prepared for analysis by adding 5 g of the sample to 150 ml of distilled water in a wide mouth 8 oz jar. The jars were marked with an identifying code, capped, shaken periodically and set aside for a soaking period of at least 1 wk. At the time that the sample was tested, the contents of the jar were mixed by shaking and 1 ml of the suspension was transferred by pipetting into 150 ml of water. After mixing, 1 ml of this suspension was transferred by pipetting into 250 ml of the 1% NaCl solution used in the test procedure. This very dilute suspension of the filter aid sample was used in the Coulter Counter test.

A particle size analysis was made by counting the particles within the given size range being sensed at the instrument settings as successive 500 microliter volumes of the filter aid suspension were drawn through a 140-μ aperture. Three counts were made at each instrument setting and were averaged. The time required for a complete particle size analysis is about 30 min. Table 2 shows the test data recorded and the calculated final results for a particle size analysis of a sample of S2-1 filter aid.

---

*Coulter Electronics Industrial Division, Chicago, Ill.

Table 2. Particle size analysis data for a sample of S2-1 filter aid using the Coulter Counter method.

Line	Particle size, μ	Counts			Average background count	Percent finer
		1st	2nd	3rd		
1	100	–	–	–	–	–
2	80	–	–	–	–	–
3	63	0	4	1	0	–
4	50	2	0	0	0	100
5	40	4	6	10	0	96
6	31	19	11	12	0	78
7	25	27	25	34	1	58
8	20	34	47	34	1	39
9	15.6	59	43	51	3	26
10	12.4	76	66	78	3	18
11	10	98	113	89	8	12
12	7.8	191	114	126	17	8
13	6.2	222	222	207	40	5.3
14	4.9	374	389	594	153	3.4
15	3.9	775	1286	942	330	1.8

The second column in the table gives the particle sizes corresponding to the various combinations of control settings used. In line 12 the particles counted – 191, 114, and 126 – represent "particles" in the size range between 7.8 and 10μ. Some of the particles counted are suspended solids in the water used to suspend the sample (or even electronic noise in the instrument). This is referred to as background and a typical background count for each size range is given. Some of the remaining counts may have been caused by one or more small particles being present in the aperture at one time and being counted as a single larger particle. This is known as "coincidence." Coincidence increases as the concentration of particles in the suspension increases. The very dilute suspension was used to reduce coincidence. The final column in the table shows the resulting percent of particles finer than the indicated particle size and was calculated from the counts given.

Two apertures were evaluated in this study to determine which should be used in making the particle size measurements. The larger of the two, a 400-μ aperture was large enough so that it did not clog and its use was therefore relatively troublefree. The smallest particle that could be counted with this aperture, however, was 8 to 10μ and, in the lower particle sizes, coincidence effects were too large to be tolerated when the sample size was large enough to avoid background effects. The Coulter Counter results included in the Interim Report[3] were obtained using the 400-μ aperture. These results are seriously in error because of coincidence effects.

The 140-μ aperture counted particles as small as 3 to 4μ. The coincidence and background effects were much smaller than they were with the 400-μ aperture but clogging was a serious problem. In spite of the clogging problems, the 140-μ aperture was used to obtain the results given in this report.

Because of the operating problems experienced using the Coulter Counter with the materials under study, the Coulter Counter was used only for the analysis of perlite filter aids. The perlite filter aids could not be analyzed using the hydrometer method. In addition, however, one grade of diatomite was analyzed using both the Coulter Counter method and the hydrometer method for the purpose of comparing the results of the two methods.

Hydrometer Method[4]

Different sized particles suspended in water settle with different velocities. As the particles settle out of suspension, the effective

bulk density of the suspension changes. A hydrometer determines the changes in the effective bulk density of a suspension of filter aid with time as the various sizes of filter aid settle out of suspension. The results of the hydrometer analysis are used to calculate the particle size distribution of the filter aid. This technique is referred to as the hydrometer method for determination of particle size distribution of granular material. The procedure depends upon Stoke's equation for use in calculating the terminal velocity of a falling sphere. A hydrometer is used to sense the changing concentration of the suspension containing the sample being analyzed. The hydrometer* used in this study is suitable for the subseive analysis of soil materials and is calibrated with a Bouyoucos scale to read in grams of soil per liter of water.

The procedure used in running the test consisted of mixing 30 g of the filter aid to be tested in a 1 liter graduated cylinder with 125 ml of a solution containing 40 g/l of sodium hexametaphosphate (Calgon)**, a deflocculating agent. After mixing, the suspension stood overnight so that the filter aid could become thoroughly wet. Then distilled water at 20°C was added to bring the level to the 1 liter mark. After mixing the contents of the cylinder for 1 min by inverting the cylinder repeatedly, the cylinder was placed in a water bath kept at 20°C and the hydrometer was carefully inserted into the suspension. Readings were begun after an elapsed time of 0.5 min and were continued until from 4 to 24 hr elapsed. Table 3 shows the recorded data and calculated results for determining the particle size distribution of a sample of J3-5 filter

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*Taylor ASTM Soil Hydrometer 152H, Taylor Instrument Companies, Rochester, N.Y.

**Registered trademark, Calgon Corp., Pittsburg, Pa.

Table 3. Particle size analysis of a sample of J3-5 filter aid using the hydrometer method.[a]

Line	Elapsed time, min	Hydrometer reading, g/l	Particle size, μ	Percent finer
1	0.5	31	73	94
2	1	30	52	90
3	2	28	37	82
4	5	23.5	24	66
5	15	16.5	14.6	40
6	30	11	10.7	20
7	60	8	7.7	9.2
8	240	6	3.9	1.8

[a] Calculations typical of those used in this method are described in ASTM Method D422-63[4].

aid using the hydrometer method. The second column contains the elapsed times since the beginning of the test and the third column contains the hydrometer readings found at these times. The values given in columns 4 and 5 are the particle size and percent of material finer than that particle size calculated using the elapsed time and the hydrometer reading.

There are a number of assumptions in Stokes' equation which are not completely fulfilled in the hydrometer method. These assumptions are:

- no interference of particles by other particles or by the walls of the container or the hydrometer itself,
- spherical particles,
- known and uniform specific gravity of particles.

Research with soil materials has shown that 50 g of dry soil per liter of suspension can be used with only negligible effects due to particle interference in a hydrometer test. Because the bulk density of the filter aids under study is less than that of the typical soil materials for which

this test was devised, less filter aid should be used by weight than soil. Experience has shown that the first assumption can be practically met if the amount of filter aid used in the test is limited to about 30 g[5].

The shape of particles of diatomite is not spherical although some of the aggregates of particles may be reasonably accurately represented as spheres. The diameter of a sphere that would fall through water at the same velocity as a platelike particle of diatomite would be smaller than the length of the plate because a plate shape is not the one which receives the minimum resistance to fall. The hydrometer test should, therefore, tend to underestimate the particle size of diatomite. Photomicrographs of diatomite analyzed by the hydrometer method confirm this.

Because of the nonuniform specific gravity of particles within a given grade of perlite filter aid (ranging from less than 1.0 to more than 2.3), the hydrometer method is not suitable for the particle size analysis of perlite filter aids. The hydrometer test was used only for the determination of particle size distributions of diatomite filter aids. It was used for the analysis of diatomite filter aids in preference to the Coulter Counter method because of the larger sample size that is employed and with the expectation that the larger sample size would yield more consistent and representative results.

Pycnometer Method

The pycnometer method was used to determine the average effective specific gravity of the filter aid samples. The method is based on gravimetric measurements made to determine the amount of water displaced from a

pycnometer flask by a given weight of sample. A detailed standard procedure developed for performing this test is given in part IV of this report.

Permeameter Method

The permeameter method was used to determine the filter cake resistance and bulk density of the filter aid samples. The method is based on measurements taken during and following a constant-pressure filtration test in which a filter cake is built up to a depth of 2.5 $\pm$ 0.1 in. by filtering a suspension containing the filter aid sample while the filtrate is collected in a volumetric cylinder. The change in the rate of filtration is measured by determining with a stop watch the time required to collect successive volumes of filtrate. The change in the rate of filtration is used in calculating the filter cake resistance. At the end of the test, the thickness of the cake is measured and the cake is dried and weighed. The thickness of the cake is used in computing the volume of the cake. The bulk density of the filter aid is equal to the weight of filter aid in the cake divided by the volume of the cake. A detailed standard procedure developed for performing this test is given in part IV of this report.

RESULTS

Particle Size Distributions

The particle size distributions of three grades of perlite filter aid were determined using the Coulter Counter method. The particle size distributions of the eight grades of diatomite filter aids were determined using the hydrometer method. In addition, one grade of diatomite was tested by both methods to compare the results obtained using the two methods (Fig. 1)*. Figures 2 through 12 show the average and range of particle size distributions for the various lots of each grade of filter aid tested. Figure 13 is a composite of the average curves for all of the grades tested.

Effective Specific Gravity

Table 4 lists the values of the effective specific gravity for each lot of filter aid tested using the standardized procedure given in Part IV of this report. Some test results have been eliminated in computing averages because they deviated too much from the other test results. The results that have been eliminated are marked with an asterisk in the table.

---

*See Appendix I.

Table 4. Effective specific gravity of the eleven grades of perlite and diatomite filter aids included in this study.

Filter aid grade	Lot number	Effective specific gravity, ρ_F Test result	Average for lot	Average for grade
S2	1	1.50	1.50	1.57
		1.52		
		1.48		
	4	1.48	1.50	
		1.82(a)		
		1.52		
	5	1.40	1.46	
		1.49		
		1.49		
	6	1.32	1.54	
		1.69		
		1.60		
	9	1.52	1.58	
		1.60		
		1.62		
	20	1.35	1.47	
		1.58		
	21	2.20	1.95	
		1.83		
		1.85		
		1.92		
S3	1	1.73	1.64	1.73
		1.64		
		1.56		
	2	1.76	1.82	
		1.82		
		1.87		
	3	1.88	1.75	
		1.64		
		1.74		
	4	1.86	1.72	
		1.66		
		1.65		

Table 4. Continued.

Filter aid grade	Lot number	Effective specific gravity, ρ_F Test result	Average for lot	Average for grade
S4	1	1.75	1.95	1.98
		2.14		
		1.97		
	2	1.94	2.01	
		2.05		
		2.04		
J4	4	2.33	2.30	2.30
		2.32		
		2.25		
		2.04[a]		
		2.11[a]		
	7	2.27	2.30	
		2.33		
		2.31		
J3	5	2.31	2.31	2.32
		2.29		
		2.34		
		2.19[a]		
		2.18[a]		
	7	2.32	2.32	
		2.33		
		2.32		
		2.33		
		2.32		
		2.28		
		2.33		
J0	1	2.30	2.30	2.30
		2.27		
		2.01[a]		
		2.32		
	4	2.29	2.31	
		2.29		
		2.33		
		2.32		
		2.40[a]		

Table 4. Continued.

Filter aid grade	Lot number	Effective specific gravity, ρ_F Test result	Average for lot	Average for grade
E6	2	2.33 2.11 2.17 2.07	2.17	2.22
	3	2.36 2.13 2.18 2.11	2.22	
	4	2.31 2.24 2.17 2.23	2.26	
E5	1	2.33 2.32 2.26 2.30 2.32	2.31	2.30
	3	2.33 2.28 2.31 2.28	2.30	
	17	2.31 2.35 2.12[a] 2.31 2.25	2.30	
E2	1	2.32 2.32 2.17[a] 2.24 2.23	2.28	2.28
	2	2.33 2.33 2.12[a] 2.09[a] 2.20	2.29	

Table 4. Continued.

Filter aid grade	Lot number	Effective specific gravity, ρ_F Test result	Average for lot	Average for grade
	3	2.36	2.30	
		2.34		
		1.72(a)		
		2.25		
		2.25		
	4	2.33	2.27	
		2.17(a)		
		2.22		
		2.29		
G4	1	2.33	2.25	2.27
		2.20		
		2.19		
		2.28		
	2	2.33	2.24	
		2.21		
		2.22		
		2.21		
	3	2.36	2.34	
		2.34		
		2.36		
		2.36		
		2.38		
		2.35		
		2.34		
		2.28		
		2.34		
		2.34		
	4	2.34	2.25	
		2.10(a)		
		2.20		
		2.20		
	5	2.28	2.26	
		2.22		
		2.28		

Table 4. Continued.

Filter aid grade	Lot number	Effective specific gravity, ρ_F Test result	Average for lot	Average for grade
G1	2	2.33	2.32	2.28
		2.32		
		1.87 (a)		
		2.18 (a)		
		2.31		
	3	2.36	2.24	
		2.22		
		2.18		
		2.21		

(a) Eliminated in computing the average

Bulk Density and Filter Cake Resistance

Table 5 lists the values of bulk density and filter cake resistance for each lot of filter aid tested using the standardized procedure given in Part IV of this report. The results reported previously in the Interim Report are about 3% (1-7%) higher than the results reported herein in the values for bulk density and by about 36% (13 to 55%) in the values for filter cake resistance (Table 6). An investigation of the new apparatus used in the standardized procedure revealed that the pressure used was too low because of a faulty pressure gage. When the pressure gage was checked with a mercury manometer, a reading of 30 psi on the gage corresponded to 139 cm, Hg whereas it should have been 155 cm, Hg. Previous work done in evaluating the test procedure can be used in determining the effect of this gage error (Table 7).

Table 5. Bulk density (γ_F) and filter cake resistance (β_o) of the eleven grades of perlite and diatomite filter aids included in this study.

Filter aid grade	Lot number	Test result γ_F pcf	Test result β_o ft^{-2}	Average for lot γ_F pcf	Average for lot β_o ft^{-2}	Average for grade γ_F pcf	Average for grade β_o ft^{-2}
S2	1	10.36	4.25×10^5	9.94	4.12×10^5	9.92	4.25×10^5
		9.52	3.99×10^5				
	4	10.34	4.51×10^5	10.20	4.47×10^5		
		10.05	4.43×10^5				
	5	9.58	4.09×10^5	9.70	4.02×10^5		
		9.80	3.86×10^5				
		9.70	3.77×10^5				
		9.71	4.38×10^5				
	6	9.72	4.37×10^5	9.90	4.42×10^5		
		9.74	4.39×10^5				
		9.78	4.43×10^5				
		10.34	4.51×10^5				
	9	9.79	4.42×10^5	9.92	4.34×10^5		
		9.84	4.28×10^5				
		10.05	4.43×10^5				
		10.01	4.24×10^5				
	20	9.38	4.06×10^5	9.44	4.05×10^5		
		9.41	4.09×10^5				
		9.52	4.00×10^5				
	21	10.26	4.22×10^5	10.34	4.31×10^5		
		10.40	4.25×10^5				
		10.36	4.25×10^5				
		10.34	4.51×10^5				
S3	1	12.36	5.48×10^5	12.56	5.50×10^5	12.64	5.67×10^5
		12.70	5.14×10^5				
		12.58	6.01×10^5				
		12.59	5.36×10^5				
	2	12.57	4.82×10^5	12.61	5.04×10^5		
		12.43	4.82×10^5				
		12.68	5.39×10^5				
		12.77	5.14×10^5				
	3	12.52	4.97×10^5	12.49	5.60×10^5		
		12.51	5.96×10^5				
		12.36	5.48×10^5				
		12.58	6.01×10^5				

Table 5. Continued.

Filter aid grade	Lot number	Test result γ_F pcf	Test result β_o ft^{-2}	Average for lot γ_F pcf	Average for lot β_o ft^{-2}	Average for grade γ_F pcf	Average for grade β_o ft^{-2}
S3 (Cont.)	4	12.94	5.93×10^5	12.90	6.54×10^5		
		12.91	7.33×10^5				
		12.71	6.39×10^5				
		13.02	6.49×10^5				
S4	1	12.94	5.93×10^5	12.90	6.54×10^5	13.00	6.50×10^5
		12.91	7.33×10^5				
		12.71	6.39×10^5				
		13.02	6.49×10^5				
	2	13.38	6.10×10^5	13.10	6.46×10^5		
		13.12	6.21×10^5				
		12.86	6.98×10^5				
		13.05	6.55×10^5				
J4	4	19.66	1.07×10^5	19.64	1.10×10^5	19.73	1.14×10^5
		19.62	1.05×10^5				
		19.64	1.19×10^5				
		19.62	1.09×10^5				
	7	20.23	1.08×10^5	19.82	1.17×10^5		
		19.73	1.18×10^5				
		19.51	1.26×10^5				
J3	5	19.09	1.19×10^5	18.98	1.29×10^5	19.94	1.18×10^5
		18.92	1.33×10^5				
		18.94	1.36×10^5				
	7	20.89	1.04×10^5	20.89	1.08×10^5		
		20.92	1.11×10^5				
		20.86	1.09×10^5				
J0	1	19.93	2.29×10^5	19.92	2.27×10^5	19.94	1.90×10^5
		19.91	2.16×10^5				
		19.88	2.46×10^5				
		19.95	2.18×10^5				
	4	20.04	1.55×10^5	19.96	1.52×10^5		
		19.99	1.57×10^5				
		19.93	1.49×10^5				
		19.88	1.49×10^5				

Table 5. Continued.

Filter aid grade	Lot number	Test result γ_F pcf	Test result β_o ft^{-2}	Average for lot γ_F pcf	Average for lot β_o ft^{-2}	Average for grade γ_F pcf	Average for grade β_o ft^{-2}
E6	2	19.43	0.71×10^5	19.28	0.71×10^5	19.30	0.70×10^5
		19.38	0.73×10^5				
		19.37	0.63×10^5				
		18.95	0.76×10^5				
	3	19.03	0.71×10^5	19.14	0.71×10^5		
		19.08	0.70×10^5				
		19.07	0.73×10^5				
		19.39	1.12×10^5*				
E6	4	19.49	0.65×10^5	19.48	0.68×10^5		
		19.59	0.69×10^5				
		19.34	0.67×10^5				
		19.48	0.70×10^5				
E5	1	25.62	1.21×10^5	25.79	1.17×10^5	23.17	1.09×10^5
		25.80	1.27×10^5				
		25.96	0.93×10^5				
		25.79	1.27×10^5				
	3	22.23	1.01×10^5	22.26	1.07×10^5		
		22.24	1.13×10^5				
		22.28	1.02×10^5				
		22.29	1.12×10^5				
	17	21.32	0.98×10^5	21.47	1.03×10^5		
		21.63	1.02×10^5				
		21.44	1.05×10^5				
		21.48	1.07×10^5				
E2	1	20.78	1.53×10^5	20.74	1.54×10^5	20.72	1.56×10^5
		20.69	1.56×10^5				
	2	20.98	1.38×10^5	20.86	1.37×10^5		
		20.98	1.25×10^5				
		20.72	1.50×10^5				
		20.78	1.34×10^5				
	3	20.78	1.53×10^5	20.78	1.54×10^5		
			1.56×10^5				

Table 5. Continued.

Filter aid grade	Lot number	Test result γ_F pcf	Test result β_o ft^{-2}	Average for lot γ_F pcf	Average for lot β_o ft^{-2}	Average for grade γ_F pcf	Average for grade β_o ft^{-2}
E2 (Cont.)	4	20.42	1.83×10^5	20.48	1.78×10^5		
		20.44	1.85×10^5				
		20.52	1.79×10^5				
		20.52	1.67×10^5				
G4	1	23.90	1.25×10^5	23.88	1.20×10^5	23.54	1.11×10^5
		24.12	1.15×10^5				
		23.76	1.32×10^5				
		23.74	1.09×10^5				
	2	23.29	0.99×10^5	23.46	1.03×10^5		
		23.28	1.06×10^5				
		23.82	1.05×10^5				
	3	23.57	0.96×10^5	23.60	0.99×10^5		
		23.66	1.03×10^5				
		23.52	0.97×10^5				
		23.63	1.01×10^5				
	4	22.99	1.16×10^5	23.13	1.15×10^5		
		22.99	1.12×10^5				
		23.44	1.16×10^5				
	5	22.98	1.16×10^5	23.64	1.20×10^5		
		23.66	1.03×10^5				
		24.12	1.15×10^5				
		23.82	1.05×10^5				
G1	2	22.07	2.69×10^5	22.24	2.58×10^5	22.29	2.29×10^5
		22.51	2.54×10^5				
		22.35	2.55×10^5				
		22.04	2.55×10^5				
	3	22.24	1.97×10^5	22.34	1.99×10^5		
		22.21	1.93×10^5				
		22.58	2.06×10^5				

Table 6. Comparison of results for bulk density (γ_F) and filter cake resistance (β_o) of eleven grades of perlite and diatomite filter aids determined using nonstandard and standard procedures.

Filter aid grade	Average γ_F, pcf			Average β_o, 10^5 ft^{-2}		
	Interim Report	Old[a]	New[b]	Interim Report[3]	Old[a]	New
S2	10.3	10.6	9.9	6.1×10^5	6.2×10^5	4.2×10^5
S3	12.8	12.8	12.6	8.0×10^5	8.0×10^5	5.7×10^5
S4	13.2	13.5	13.0	9.0×10^5	9.3×10^5	6.5×10^5
J4	21.1	20.8	19.7	1.7×10^5	1.5×10^5	1.1×10^5
J3	20.6	20.5	19.9	2.2×10^5	1.5×10^5	1.2×10^5
J0	20.9	20.5	19.9	2.5×10^5	2.5×10^5	1.9×10^5
E6	19.9	19.4	19.3	1.0×10^5	0.9×10^5	0.7×10^5
E5	22.1	23.7	23.2	1.5×10^5	1.7×10^5	1.1×10^5
E2	21.4	21.1	20.7	2.8×10^5	2.4×10^5	1.6×10^5
G4	23.8	23.8	23.5	1.4×10^5	1.4×10^5	1.1×10^5
G1	22.6	22.8	22.3	2.7×10^5	2.6×10^5	2.3×10^5

(a) Some of the filter aid lots were used up in the tests reported in the Interim Report so they could not be retested using the new standardized procedures. Therefore, the average results reported in the Interim Report cannot be compared directly with the average results using the standardized procedure. To provide a basis for comparison, the "old" averages shown above were computed using the results used in computing the averages for the Interim Report. The filter aids for which the "old" averages were computed were the same ones used in computing the "new" averages.

(b) Using standard procedure described in Part IV of this Final Report.

Table 7. Bulk density (γ_F) and filter cake resistance (β_o) of filter aid E5 lot 37 used in evaluating the test procedure.

Run number	Operator	Pressure, cm Hg	Cake thickness, in.	Test result γ_F pcf	Test result β_o ft^{-2}	Average result γ_F pcf	Average result β_o ft^{-2}
6	A	52	0.7	20.6	1.7×10^5	20.9	2.4×10^5
3	A	52	0.9	20.8	1.9×10^5		
8	A	52	1.3	21.0	2.0×10^5		
5	A	52	1.3	20.7	3.0×10^5		
7	A	52	1.8	21.2	2.9×10^5		
4	A	52	1.8	21.2	2.8×10^5		
14	A	103	0.9	20.8	1.7×10^5	21.4	1.7×10^5
13	A	103	0.9	21.6	1.6×10^5		
12	A	103	1.4	21.8	1.7×10^5		
10	A	103	1.4	21.5	1.6×10^5		
11	A	103	1.9	21.2	2.0×10^5		
9	A	103	2.0	21.8	1.8×10^5		
16	A	154	0.8	22.3	1.4×10^5	22.0	1.4×10^5
15	A	154	0.9	21.3	1.2×10^5		
18	A	154	1.4	22.3	1.3×10^5		
17	A	154	1.5	21.9	1.5×10^5		
1	A	152	1.7	21.9	1.6×10^5		
2	A	152	2.0	21.8	1.5×10^5		
20	A	154	2.0	22.2	1.4×10^5		
19	A	154	2.0	22.2	1.5×10^5		
22	A	191	0.6	21.5	1.2×10^5	22.3	1.3×10^5
21	A	192	0.8	22.3	1.2×10^5		
23	A	192	1.4	22.3	1.4×10^5		
24	A	192	1.4	22.5	1.2×10^5		
26	A	193	2.0	22.7	1.3×10^5		
25	A	191	2.1	22.3	1.5×10^5		
38	B	109	1.8	21.5	2.1×10^5	21.5	2.1×10^5
34	B	154	0.4	21.6	1.7×10^5	22.0	1.6×10^5
33	B	154	0.8	21.5	1.4×10^5		
32	B	154	1.0	22.5	1.3×10^5		
31	B	154	1.4	21.9	1.5×10^5		
37	B	154	1.5	22.0	1.6×10^5		
30	B	154	1.8	22.3	1.8×10^5		
28	B	154	1.8	21.8	1.6×10^5		
35	B	154	1.9	22.3	1.7×10^5		
39	B	154	2.0	22.0	1.9×10^5		
27	B	154	2.0	22.3	1.5×10^5		
29	B	154	2.5	22.3	1.7×10^5		
36	B	176	1.7	22.0	1.7×10	22.0	1.7×10^5

Table 7. Continued.

Run number	Operator	Pressure, cm Hg	Cake thickness, in.	Test result γ_F pcf	Test result β_o ft^{-2}	Average result γ_F pcf	Average result β_o ft^{-2}
41	C	155	1.8	22.4	1.5×10^5	22.5	1.6×10^5
45	C	155	1.9	22.7	1.6×10^5		
44	C	155	2.0	23.1	1.6×10^5		
49	C	155	2.0	22.7	1.5×10^5		
50	C	155	2.1	22.7	1.5×10^5		
40	C	155	2.1	22.3	1.5×10^5		
46	C	155	2.2	22.5	1.6×10^5		
51	C	155	2.2	22.3	1.5×10^5		
48	C	155	2.3	22.8	1.6×10^5		
42	C	155	2.5	22.2	1.6×10^5		
43	C	155	2.5	22.0	1.7×10^5		
47	C	155	2.6	22.3	1.6×10^5		

Based on the results obtained by operator A, a reduction in pressure from 154 to 103 cm, Hg, reduced the bulk density from an average value of 22.0 pcf to 21.4 pcf. Therefore:

$$\frac{\Delta\bar{\gamma}_F\ (100\%)}{\Delta p\ \bar{\gamma}_F} = \frac{(0.6\ \text{pcf})(100\%)}{(51\ \text{cm Hg})(22.0\ \text{pcf})}$$

$$= 0.053\ \%\ \text{per cm Hg.}$$

The effect of the gage error of 16 cm, Hg, should have caused an error of no more than 1% in the bulk density (and about the same amount of error in the filter cake resistance)*.

Further investigation of the experimental procedures and equipment used in obtaining the old and the new results revealed the reason for the difference in the results. Galvanized iron pipe nipples had been used in

*In Table 7 the average values for β_o decrease with increasing pressure. This is contrary to theory and must be attributed to uncontrolled factors that affected the measurement (probably suspended solids in the distilled water used and rust in the sample tank resulting from use of galvanized pipe in its construction). The standard test apparatus and procedure were subsequently modified to eliminate corrosive materials from the apparatus and to provide for prefiltration of the distilled water through a 0.45μ Millipore membrane.

fabricating the old sample holder inlet and outlet. The nipples were rusty. Minute but significant amounts of rust were incorporated into the filter aid sample during the process of testing a sample as the suspension was poured into the sample holder through one galvanized iron pipe nipple, was mixed in the water using a magnetic stirrer, and was forced out of the sample holder through the other galvanized iron pipe nipple.

This problem ephasized the need for keeping the apparatus scrupulously clean and for keeping contaminants out of the distilled water used in the test. The problem described above did not arise in the new apparatus because the fittings used were corrosion resistant – i.e., brass, stainless steel, etc. Because of this problem, however, the standard test procedure was further modified to include the filtration of the water used in the test through a membrane filter to avoid inconsistent results due to particulate matter that might find its way into the distilled water supply.

SUMMARY OF TEST RESULTS

Table 8 is a summary of the average values of effective size (D_{10}), mean particle size (D_{50}), uniformity coefficient (D_{60}/D_{10}), effective specific gravity (s_F), bulk density (γ_F), and filter cake resistance (β_o) for each of the 11 grades of filter aids tested in this study.

Table 8. Average[a] physical properties of the eleven grades of perlite and diatomite filter aids included in this study.

Filter aid grade	D_{10}, μ	D_{50}, μ	D_{60}/D_{10}	s_F	γ_F pcf	β_o ft^{-2}
S2	10	28	3.3	1.6	9.9	4.2×10^5
S3	9	24	3.1	1.7	12.6	5.7×10^5
S4	9	24	3.1	2.0	13.0	6.5×10^5
J4	10	19	2.3	2.3	19.7	1.1×10^5
J3	7	16	2.7	2.3	19.9	1.2×10^5
J0	6	14	3.0	2.3	19.9	1.9×10^5
E6	11	24	2.6	2.2	19.3	0.7×10^5
E5	9	20	2.7	2.3	23.2	1.1×10^5
E2	8	16	2.1	2.3	20.7	1.6×10^5
G4	7	21	3.5	2.3	23.5	1.1×10^5
G1	5	14	3.5	2.3	22.3	2.3×10^5

[a] The values in this table have been rounded off to indicate the relative precision. The measured values for individual lots of filter aid from which those averages were computed were determined to at least one additional decimal place.

ACKNOWLEDGMENT

This work has been supported by the Engineering Research Institute, Iowa State University, in part through funds made available by the US Army Engineer Research and Development Laboratories through Research Contract DAAK02-67-C-0408 and by the Federal Water Pollution Control Administration through FWPCA Research Grant WP-00196 and Research Fellowship 5-F1-WP-26,104 (H. R. Bridges).

The authors wish to express their appreciation to Harold Bridges (FWPCA Research Fellow), Madan L. Arora (Research Graduate Assistant), Jerry Yuan-cheng Huang (Research Assistant), and to the many other graduate and undergraduate students who contributed to the success of this study.

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   Part II. "Determination of Effective Specific Gravity of Filter Aids:" E. R. Baumann, C. S. Oulman, J. Shouse).

   Part III. "Determination of Bulk Density and Filter Cake Resistance of Precoat Filters:" C. S. Oulman, E. R. Baumann.

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APPENDIX

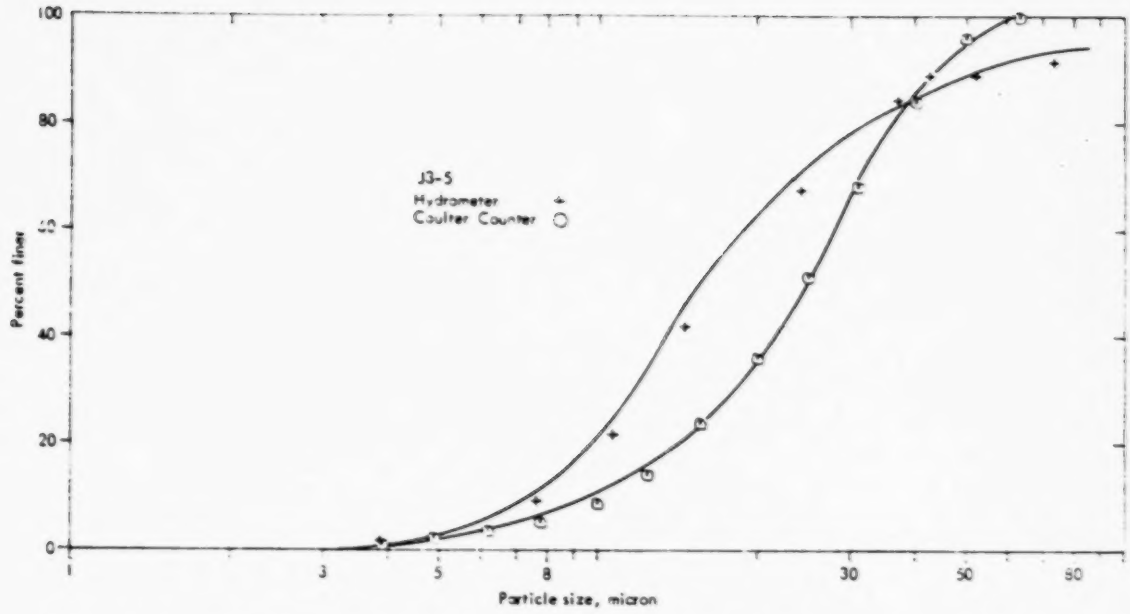

Fig. 1. Comparison of particle size distributions for one lot of J3-5 of filter aid obtained using the Coulter Counter and hydrometer methods.

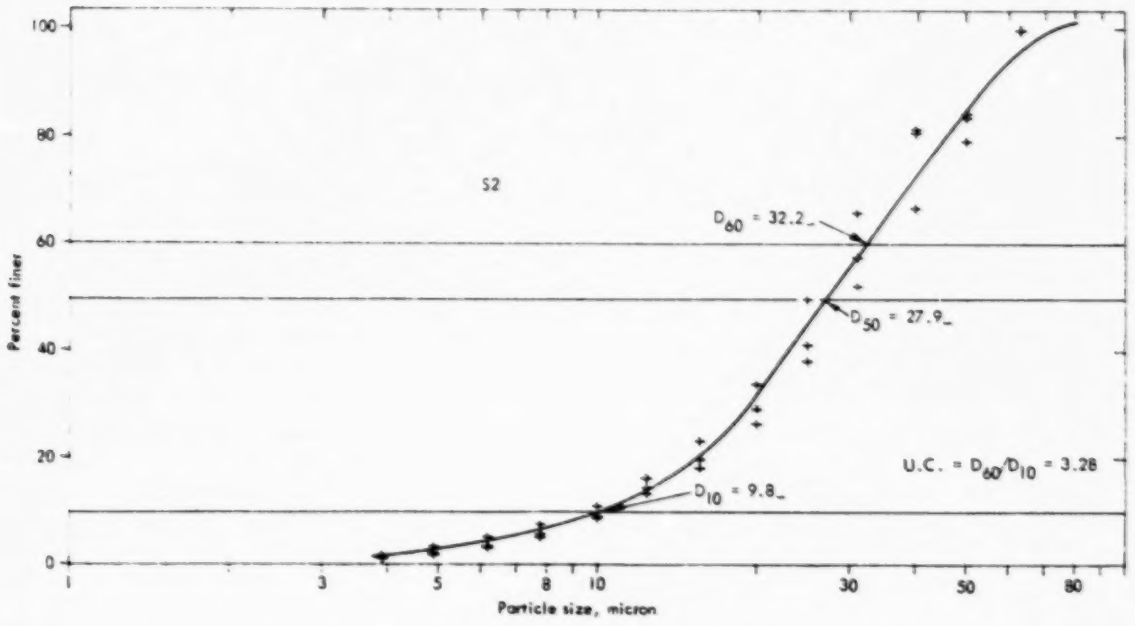

Fig. 2. Particle size distribution of S2 by the Coulter Counter method.

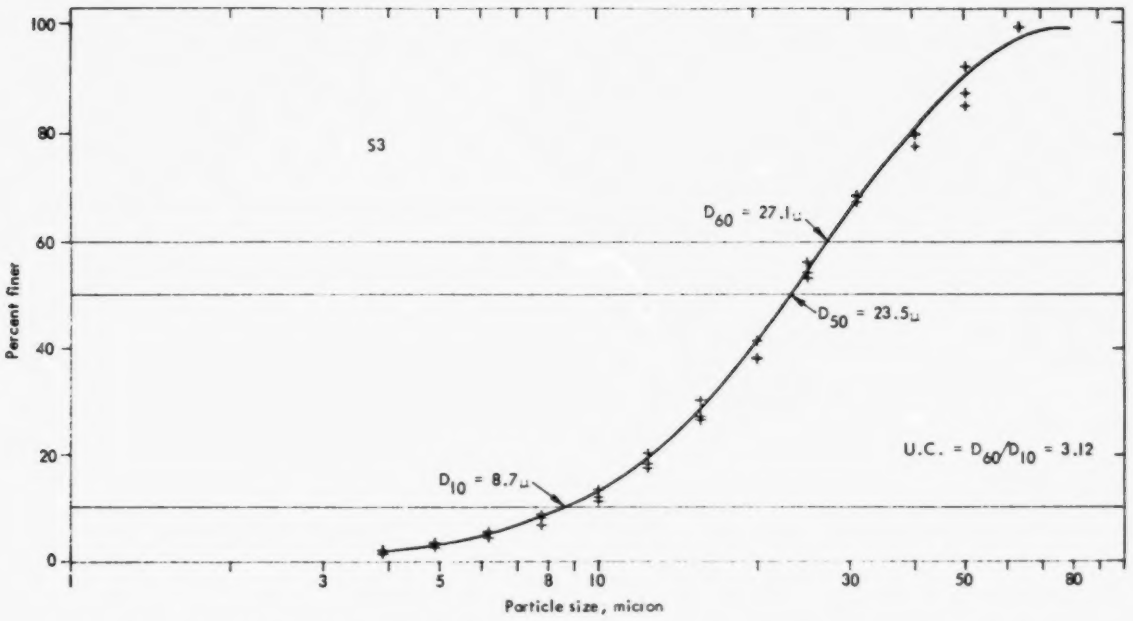

Fig. 3. Particle size distribution of S3 by the Coulter Counter method.

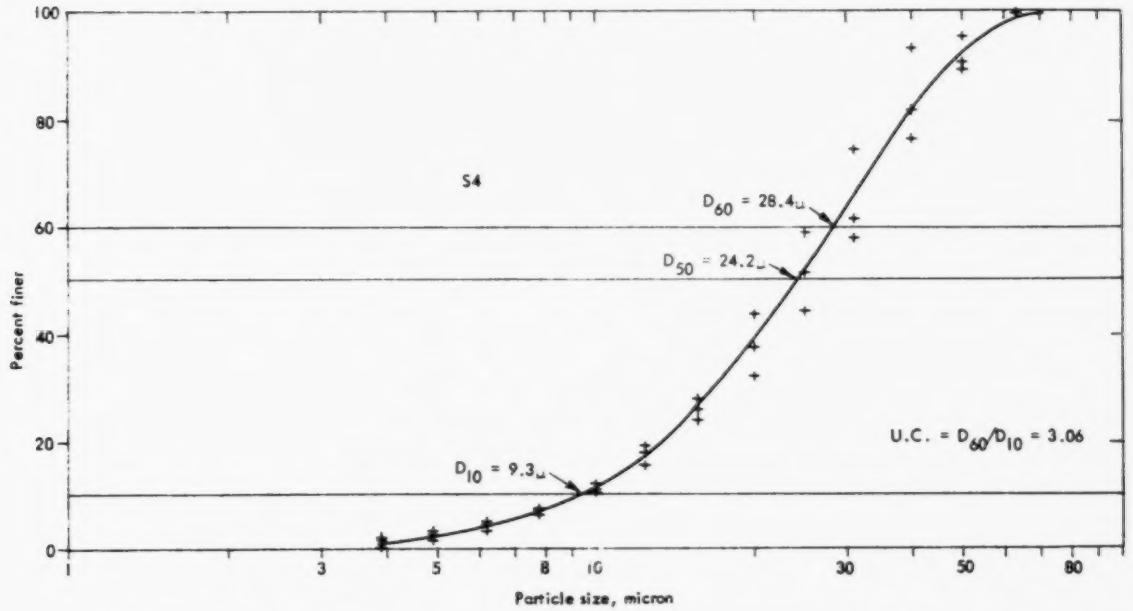

Fig. 4. Particle size distribution of S4 by the Coulter Counter method.

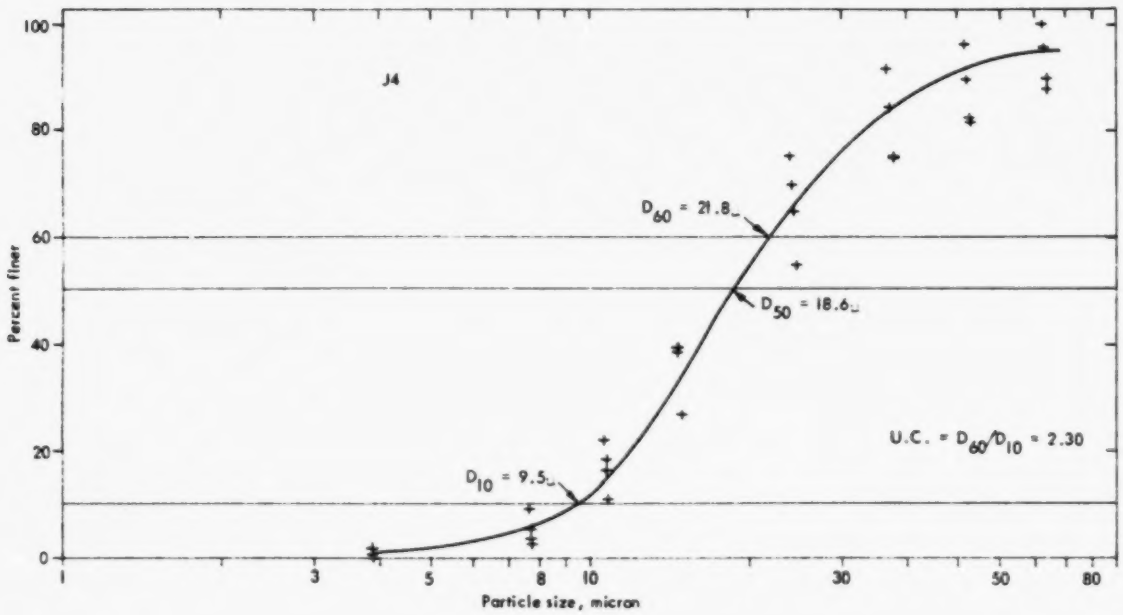

Fig. 5. Particle size distribution of J4 by the hydrometer method.

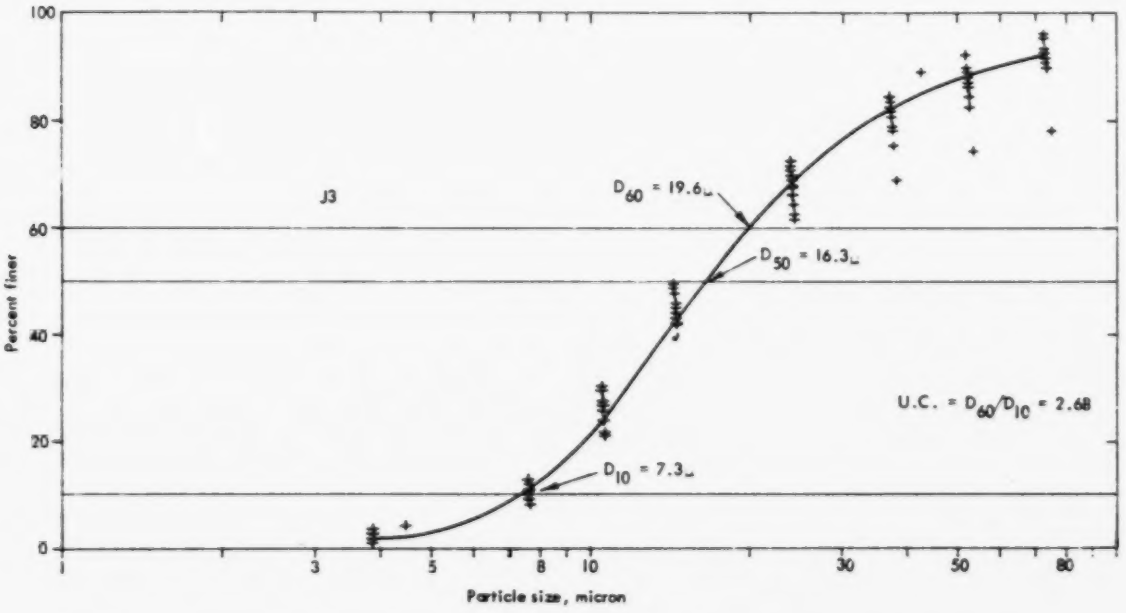

Fig. 6. Particle size distribution of J3 by the hydrometer method.

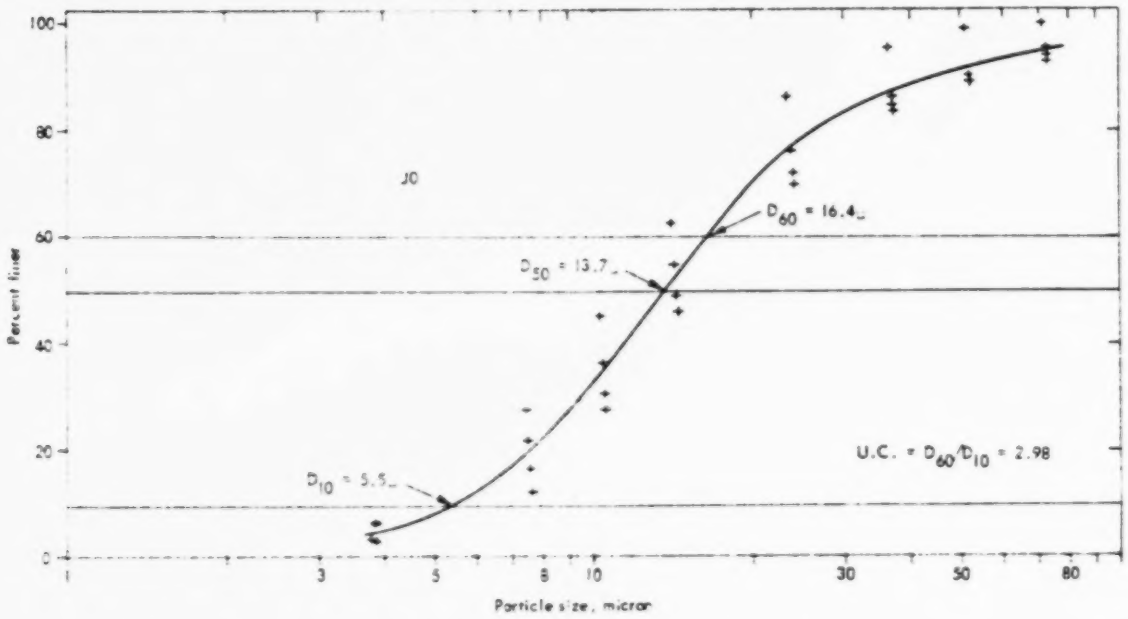

Fig. 7. Particle size distribution of J0 by the hydrometer method.

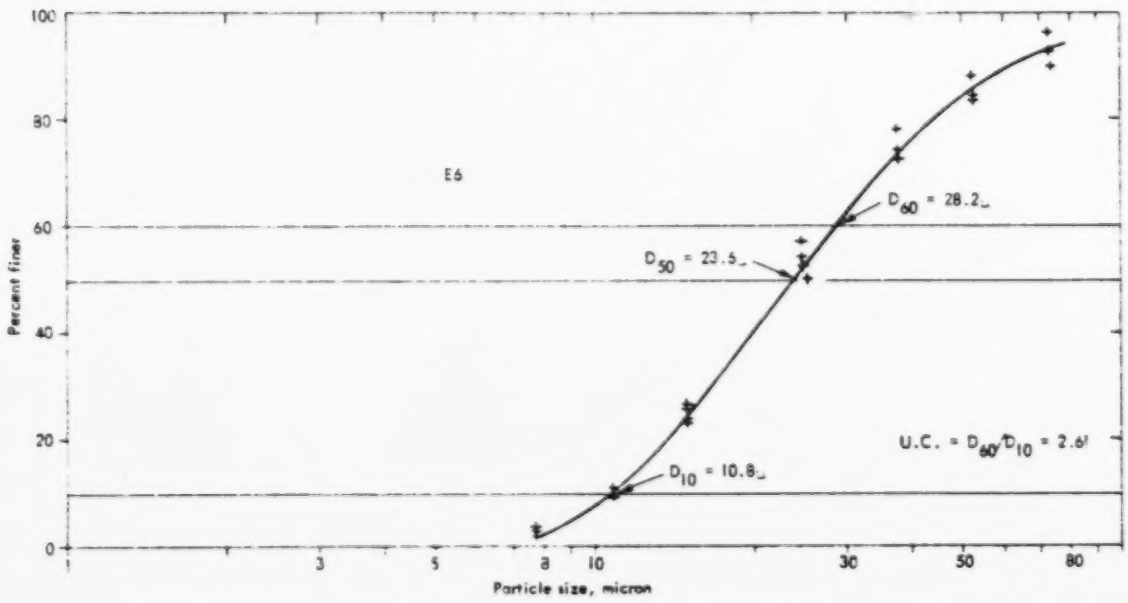

Fig. 8. Particle size distribution of E6 by the hydrometer method.

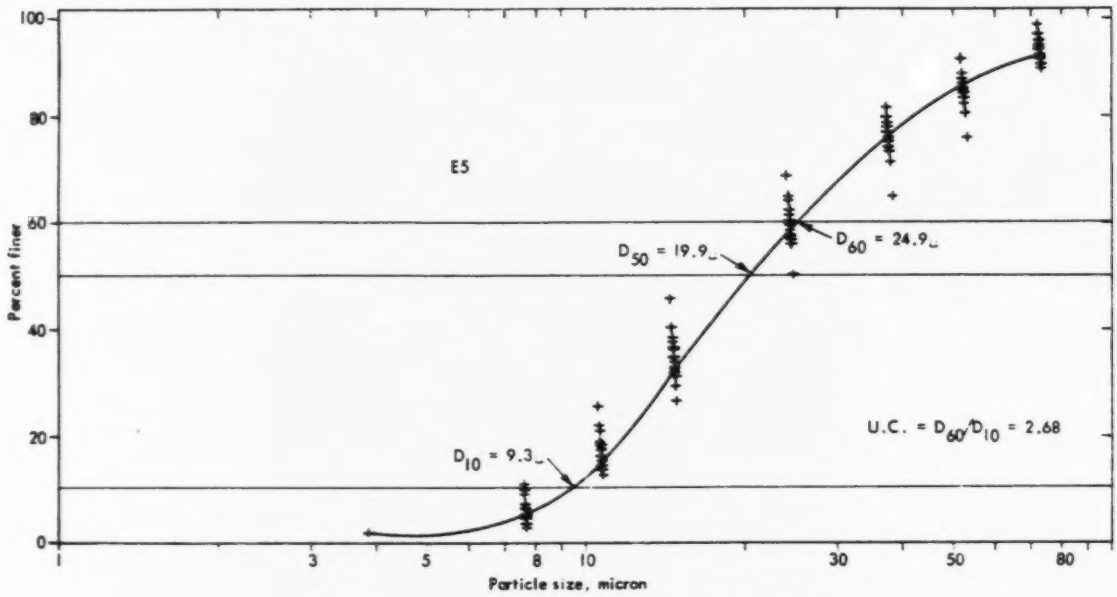

Fig. 9. Particle size distribution of E5 by the hydrometer method.

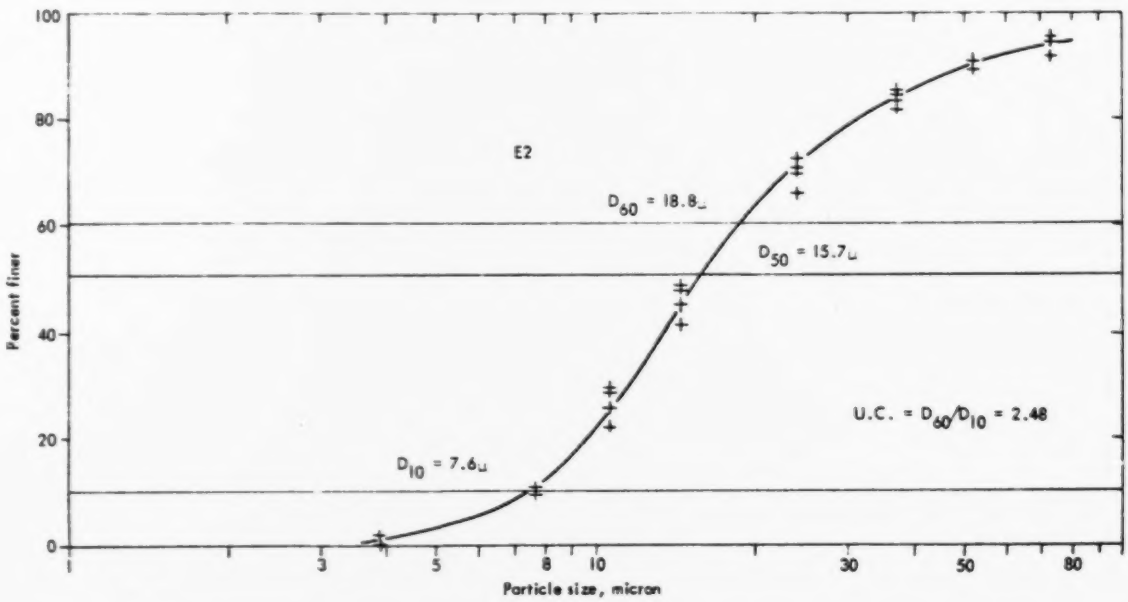

Fig. 10. Particle size distribution of E2 by the hydrometer method.

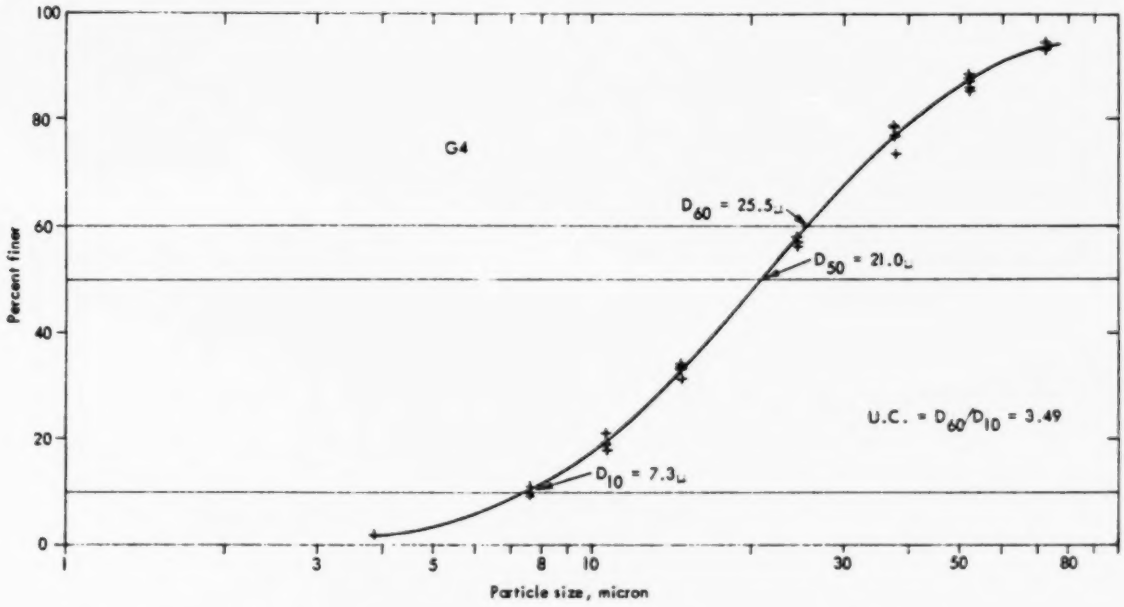

Fig. 11. Particle size distribution of G4 by the hydrometer method.

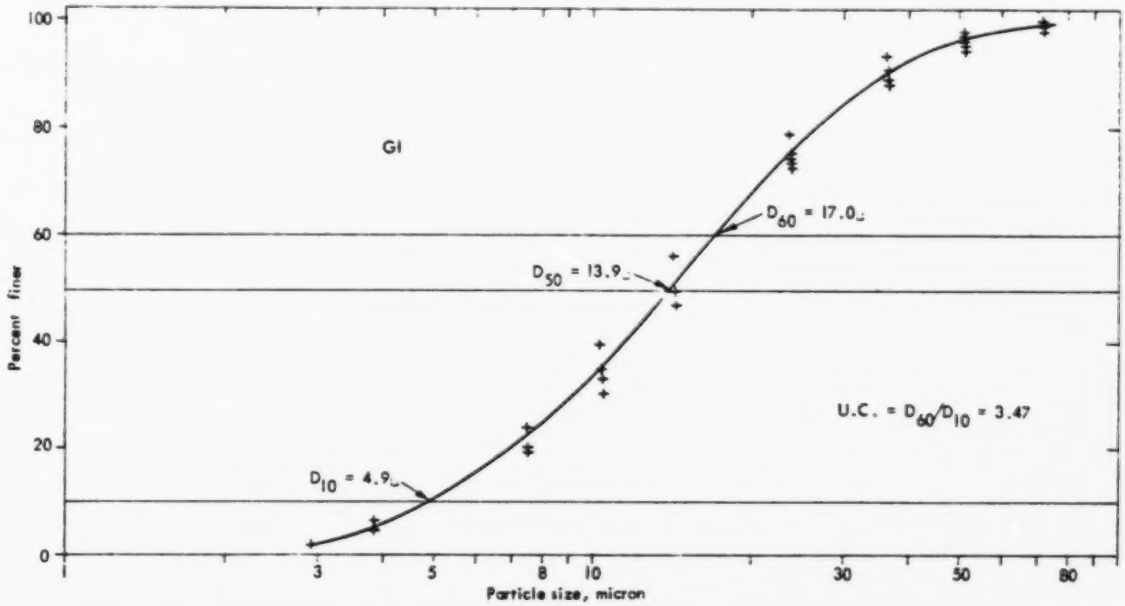

Fig. 12. Particle size distribution of G1 by the hydrometer method.

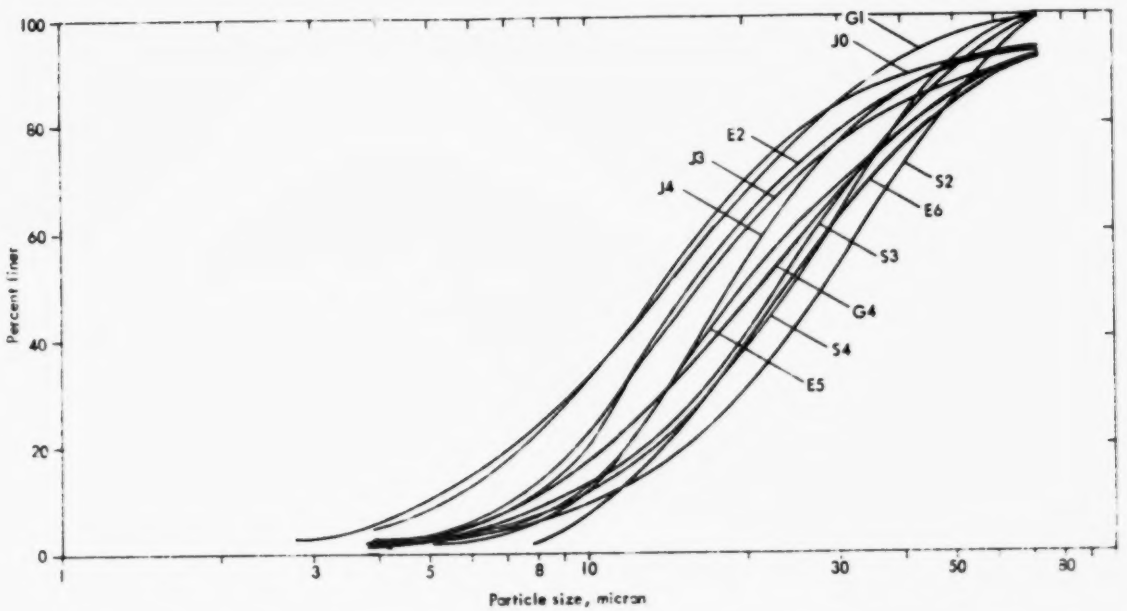

Fig. 13. Average particle size distributions for all grades of filter aids tested.